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Epidemiological survey of the feasibility of broadband ultrasound attenuation measured using calcaneal quantitative ultrasound to predict the incidence of falls in the middle aged and elderly

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ABSTRACT

Objectives: We investigated whether calcaneal quantitative ultrasound (QUS-C) is a feasible tool for predicting the incidence of falls.

Design: Prospective epidemiological cohort study.

Setting: Community-dwelling people sampled in central western Taiwan.

Participants: A cohort of community-dwelling people who were ≥40 years old (men: 524; women: 676) in 2009–2010. Follow-up questionnaires were completed by 186 men and 257 women in 2012.

Methods: Structured questionnaires and broadband ultrasound attenuation (BUA) data were obtained in 2009–2010 using QUS-C, and follow-up surveys were done in a telephone interview in 2012. Using a binary logistic regression model, the risk factors associated with a new fall during follow-up were analysed with all significant variables from the bivariate comparisons and theoretically important variables.

Primary outcome measures: The incidence of falls was determined when the first new fall occurred during the follow-up period. The mean follow-up time was 2.83 years.

Results: The total incidence of falls was 28.0 per 1000 person-years for the ≥40 year old group (all participants), 23.3 per 1000 person-years for the 40–70 year old group, and 45.6 per 1000 person-years for the ≥70 year old group. Using multiple logistic regression models, the independent factors were current smoking, living alone, psychiatric drug usage and lower BUA (OR 0.93; 95% CI 0.88 to 0.99, $p<0.05$) in the ≥70 year old group.

Conclusions: The incidence of falls was highest in the ≥70 year old group. Using QUS-C-derived BUA is feasible for predicting the incidence of falls in community-dwelling elderly people aged ≥70 years.

Strengths and limitations of this study

- The different risk factors for falling incidence were analysed in the 40–70 year old and the ≥70 year old groups.
- The use of calcaneal quantitative ultrasound (QUS-C)-derived broadband ultrasound attenuation for predicting the incidence of falls in community dwelling elderly people aged ≥70 years is examined.
- Whether QUS-C measured using other brands or at different sites in different populations would yield the same findings is unknown and warrants additional study.

INTRODUCTION

It is estimated that around one-fifth[1] to one-third[2] of elderly people fall at least once every year. Fall-related injuries, including soft-tissue injury, bone fractures, intracranial haemorrhage, functional decline, disability and death,[2] are hazardous and life threatening. Therefore, developing a method to determine the clinical risk factors related to falls is important.

Many risk factors for falls have been reported: older age,[3] sex,[1 3] lower body weight,[1] living alone,[3] arthritis,[4] previous falls,[2] using antipsychotics, antidepressants and other psychiatric medications,[2] stroke,[5] hyperglycaemia,[1] sarcopenia,[5] nutritional deficiency (hypoalbuminemia or anaemia),[2 6] and impaired balance or gait.[2] Habitual smoking and alcohol consumption might result in frailty[7] that leads to falls.[8] Over the past decades, quantitative ultrasound (QUS) has emerged as a reliable method of assessing skeletal status in osteoporosis and the risk of fractures in elderly women.[9–12] The interrelationships between QUS and quadriceps muscle strength and gait speed are believed to be associated with falls.[4 10] However, existing evidence is mostly hospital based[6 12] or from cross-sectional studies.[1 2 5 9–11] Furthermore, there are few community surveys on the incidence of falls.[8 13–16] Most studies on the incidence of falls provide data from intervention programmes,[16] focused only on the elderly and not on middle-aged people. Although several risk factors related to the incidence of falls have been reported,[8 13–16] whether the risk factors related to falling might be different between Asian and Western populations[13 14] or between middle aged people and the elderly are inconclusive.

QUS is a convenient tool for screening community-dwelling elderly people for osteoporosis[17] and related osteoporotic fractures.[18–22] Osteoporosis is defined as low bone mass or fragile bone quality;[23] thus, QUS, and especially calcaneal QUS (QUS-C),[24] might help clinical decision-making when dual-energy X-ray absorptiometry and vertebral fracture assessment disagree about a diagnosis of osteoporosis.[25] Ou *et al*[11] recently reported that QUS-C is a convenient screening tool in association with the prevalence of falls in community-dwelling middle-aged and elderly people. Based on the epidemiological cohort,[11] in the present study, we investigated the incidence of falls and the feasibility of using of QUS-C for predicting falls in middle-aged and elderly people. We hypothesised that QUS-C-derived broadband ultrasound attenuation (BUA) would be a convenient parameter for predicting the incidence of falls.

MATERIALS AND METHODS

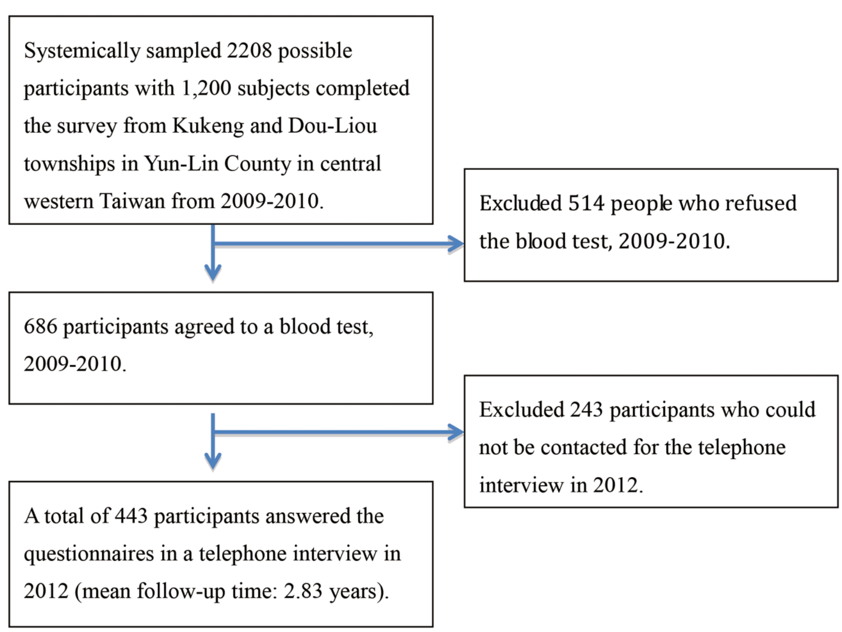
Study design and population

Two thousand, two hundred and eight subjects were selected using a step by step, stratified systemic cluster sample of households from 2009 to 2010, with a final cohort population of 1200 (including 686 who agreed to receive a blood test) from Kukeng and Dou-Liou townships in Yun-Lin County in central western Taiwan.[11] The raw response rate was 54.3%. Of the 686 enrolees who underwent a blood test in 2009–2010 and provided written informed consent, 443 (men: 186; women: 257) answered the follow-up questionnaires in a telephone interview in 2012 (figure 1). There were no significant differences in the basic characteristics between the 514 enrolees who did not take a blood test and the 686 who did; or, except for a minor difference in age, between the 443 enrolees who were followed up and the 243 who were not. The 243 enrolees who were not followed up were slightly but significantly younger (57.71±11.46 years old) than the original 1200 participants (59.30 ±11.40 years old) (p<0.01). The follow-up time, defined by the date of a new fall or the date of the telephone interview if there was no new fall, ranged from 0.91 to 3.48 years (mean: 2.83 years). This study was approved by the Institutional Review Board of National Cheng Kung University Hospital (A-ER-100-347). Each participant signed a written informed consent form.

Measurements

From 2009 to 2010, participants were asked to complete a structured questionnaire[11] that asked about lifestyle habits (exercise, smoking and alcohol drinking), living and socioeconomic status, past medical conditions, drug history and fracture history. Dichotomous variables were, for example, exercise (participants were defined as

Figure 1 Flow chart of baseline and follow-up study populations.



moderate exercisers if they exercised more than three times per week), smoking (participants were defined as a smoker if they smoked ≥20 cigarettes per month for ≥6 months), drinking (participants were defined as a drinker if they consumed alcohol at least once per week for >6 months), and living alone (participants were defined as living alone if they lived with no other person).[11] All participants underwent anthropometric and body composition measurements: skeletal muscle mass (SMM) measured using an 8-polar multi-frequency bioelectrical impedance analysis (Inbody720; Biospace, Seoul, Korea).[26] The SMM (kg) was estimated using Janssen's equation[27] and was validated in Taiwan:[26]

$$\mathrm{SMM} = \left[\frac{\mathrm{Ht}^2}{\mathrm{R} \times 0.401} + (\mathrm{sex} \times 3.825) + (\mathrm{age} \times -0.071)\right] + 5.102$$

where height is in cm; resistance is in ohms; for sex, men=1 and women=0; and age is in years. QUS-C-derived BUA (CUBA Clinical scanner MK2.6; McCue Ultrasonics, Winchester, UK) and coefficients of variation (1.3%) were obtained at the same time by a single QUS technician during 2009–2010.

Baseline haemoglobin and serum albumin were measured in 2009–2010 and used as a reference index of nutritional status.[28 29] Participants were considered anaemic if haemoglobin (Hb) was <13 g/dL in men and <12 g/dL in women.[28] Participants were considered hypoalbuminaemic if their serum albumin was <3.5 mg/dL.[29] Participants who reported a fall during the baseline survey were defined as having a history of falls if they also met any of the two following conditions: (1) they unpredictably tilted downward when standing up, sitting, or walking; or (2) they unintentionally contacted the floor with their body when changing position.[11] The same researcher who conducted the baseline interviews used, in the 2012 telephone interviews, the follow-up structured questionnaire that asked about new falls. Participants were defined as new fallers if they fell during the follow-up period, and as non-fallers if they had no recorded falls. We calculated the incidence of falls in person-years, based on Merom *et al*,[30] using the following formula:

$$\left[\frac{\text{number of new fallers}}{\begin{array}{c}\text{(average duration of telephone}\\ \text{follow-up} \times \text{number of non-fallers}\\ +\text{average duration before new fall}\\ \times\text{number of new fallers)}\end{array}}\right] \times 1000(‰)$$

The time interval (years) before the new fall was defined as from the month during which participants underwent a free community osteoporosis evaluation until the new fall occurred. The time interval (year) of the telephone follow-up was defined as from the middle of the month during which participants underwent the free community osteoporosis evaluation until telephone contact.

Statistical analysis

Data were collected and analysed using SPSS V.16 for Windows (SPSSWIN, V.16.0, Chicago, Illinois, USA). The continuous variables were expressed using mean±SD, and the categorical variables were expressed as percentages. To differentiate potentially different risk factors, participants were assigned to one of two age groups: middle aged (40–70 years old) or elderly (≥70 years old) because the elderly are more susceptible to osteoporosis and advised to have a vertebral fracture assessment to reduce the diagnostic discrepancy of osteoporosis.[24] Comparisons of categorical variables between groups were analysed using χ^2 and Fisher's exact tests, and continuous variables were analysed using an independent t test. The associated risk factors for a new faller were analysed using a binary logistic regression model with all significant variables from the bivariate comparisons and with theoretically important variables. Significance was set at p<0.05 (two tailed).

RESULTS

Of the 443 participants, the incidence of falls was 28.0 per 1000 person-years in the ≥40 year old group, 23.3 in the 40–70 year old group, and 45.6 in the ≥70 year old group. For participants with a history of falls, the incidence was 56.9 per 1000 person-years, and for those without a history of falls, it was 20.9. The univariate analysis showed a significantly higher fall history for new fallers in the 40–70 year old group (table 1). There is also a significant difference between new fallers and non-fallers ≥70 years old and living alone, and 40–70 years old with anaemia.

A binary logistic regression analysis to determine the independent factors for the incidence of falls—not used if the number of cases was less than one: cerebrovascular accident, osteoarthritis and arrhythmia—shows that the independent predictors of falls in the overall population were being male, current smoking, current alcohol consumption, living alone, a history of falls and anaemia (table 2). In the 40–70 year old group, the independent factors were being male, current alcohol consumption, fall history and fracture history. In the ≥70 year old group, the independent factors were current smoking, living alone, psychiatric drug user and QUS-C-derived BUA (OR 0.93; 95% CI 0.88 to 0.99).

DISCUSSION

We found that the incidence of falls was 28.0 per 1000 person-years for the ≥40 year old group (all participants), 23.3 for the 40–70 year old group, and 45.6 for the ≥70 year old group. The incidence of falls in our study was lower than that found in Western studies,[31] perhaps because Asians live in crowded conditions[14] and fewer elderly people live alone in Asia (5.6% of our participants) than in the West (Caucasian: 53%).[3] Furthermore, incidence-of-fall studies typically focus on interventional effects on the elderly with a history of

Table 1 Characteristics between fallers and non-fallers in 443 men and women during follow-up

Variables	≥70 years old (n=94)		40–70 years old (n=349)	
	New faller (%)	Non-faller (%)	New faller (%)	Non-faller (%)
Number of cases	12 (12.8)	82 (87.2)	23 (6.6)	326 (93.4)
Age (years)	77.1 (4.9)	75.0 (4.4)	53.5 (7.4)	53.0 (7.5)
Male	6 (50.0)	45 (54.9)	5 (21.7)	130 (39.9)
Body height (cm)	154.85 (7.73)	156.66 (8.71)	157.60 (6.85)	159.56 (7.70)
Skeletal muscle mass (kg)	21.93 (3.60)	22.28 (4.70)	22.7 (4.9)	23.3 (4.9)
Living alone	5 (41.7)**	7 (8.5)	1 (4.3)	12 (3.7)
Current smoking	2 (16.7)	5 (6.1)	4 (17.4)	40 (12.3)
Current alcohol consumption	1 (8.3)	7 (8.5)	6 (26.1)	46 (14.1)
Moderate exercise habit	1 (8.3)	20 (24.4)	7 (30.4)	116 (35.6)
Fall history	6 (50.0)	24 (29.3)	8 (34.8)*	51 (15.6)
Fracture history	3 (25.0)	15 (18.3)	9 (39.1)	67 (20.6)
Diabetes mellitus history	1 (8.3)	11 (13.4)	1 (4.3)	22 (6.7)
Hypertension history	7 (58.3)	33 (40.2)	2 (8.7)	62 (19.0)
Cerebrovascular accident history	0 (0)	1 (1.2)	0 (0)	3 (0.9)
Arrhythmia history	0 (0)	2 (2.4)	2 (8.7)	15 (4.6)
Osteoarthritis history	0 (0)	4 (4.9)	0 (0)	10 (3.1)
Psychiatric drug user	2 (16.7)	3 (3.7)	1 (4.3)	17 (5.2)
Anaemia†	6 (50.0)	23 (28.0)	6 (26.1)*	29 (8.9)
Albumin (mg/dL)	4.38 (0.19)	4.46 (0.23)	4.57 (0.25)	4.57 (0.22)
QUS-C-derived BUA (dB/MHz)	52.17 (18.35)	63.84 (20.29)	73.35 (14.09)	70.94 (16.68)

Continuous variables, mean (SD), were analysed using an independent t test; categorical variables, n (%), were analysed using a χ^2 test.
*p<0.05, **p<0.01.
†Anaemia in men if haemoglobin (Hb) <13 g/dL, and in women if Hb <12 g/dL.
BUA, broadband ultrasound attenuation; QUS-C, calcaneal quantitative ultrasound.

falls.[14 15] In contrast, our epidemiological study was community based and included middle-aged (40–70 years old) participants in addition to participants with and without a history of falls, which might have yielded a lower incidence of falls.

Recall bias might also be a concern when trying to determine the incidence of falls during the study period. Different researchers have used different methods to periodically follow up participants and more frequently obtain a record of falls.[14] In contrast, in the present study, the same trained professional asked participants about their falls in telephone interviews. A fall with injuries is clinically relevant and will easily be remembered for years. Because most falls do not result in injuries, only major falls will be reported by participants and is worth investigating, as in this study.

Consistent with other studies,[12 13 15 16] men were negatively associated with falls in our ≥40 year old study population. Current smoking and current alcohol consumption are risk factors associated with frailty,[7] which is highly associated with falls.[16] Anaemia is common in the frail elderly,[7] and is positively associated with the incidence of falls.[32] Histories of using psychiatric medications[14] and living alone[3 14] are positively associated with the incidence of falls in the elderly. A history of falls is known to be an independent risk factor for future falls.[33] A history of fractures was a risk factor for future falls in a cross-sectional study.[11] All of these risk factors for falls are compatible with our findings. Why these risk factors were different in the ≥70 year old and the 40–70 year old groups might be because the number of cases for several variables was insufficient to allow us to draw any significant conclusions despite the consistent direction of the OR for most of the variables. However, a higher prevalence of insomnia[34] in elderly people increases their use of psychiatric medications and, in turn, their probability of falling.[2] The primary fall-inducing substance in the ≥70 year old group was psychiatric medication, and in the 40–70 year old group it was alcohol.[35] Therefore, in this study it is reasonable to use alcohol consumption as an independent risk factor for the incidence of falls in the 40–70 year old group and psychiatric drug use in the ≥70 year old group.

This is the first study to report that the QUS-C-derived BUA is a predictor of falls. After adjusting for the major factors of current smoking, psychiatric drug use and a history of falls, the QUS-C-derived BUA continued to be a significant independent factor for predicting the incidence of falls in elderly people. The OR of QUS-C-derived BUA was only 0.93 for our 443 participants, but its feasibility is practical for fall prevention in clinical practice. Because there were no significant demographic differences between the 1200 members of the randomly sampled cohort, our findings would be consistent even with a larger sample size. However, there was no significant correlation between QUS-C-derived BUA and the incidence of falls in the 40–70 year old group. It is possible that the incidence of falls in this age group was too low to be significant in a moderate sample size in this study. Nevertheless, our findings

Table 2 Logistic regression models of associated factors, including QUS-C, for incidence of falls in three different age groups

Variables	≥40 years old (n=443) OR (95% CI)	≥70 years old (n=94) OR (95% CI)	40–70 years old (n=349) OR (95% CI)
Nagelkerke R^2 value	0.20	0.50	0.20
Age (years)	1.03 (0.99 to 1.08)	0.99 (0.78 to 1.26)	1.07 (0.99 to 1.16)
Sex (men=1, women=0)	0.15 (0.04 to 0.62)**	0.84 (0.04 to 6.36)	0.05 (0.01 to 0.44)**
Body height (cm)	1.04 (0.96 to 1.11)	1.10 (0.95 to 1.28)	1.04 (0.94 to 1.15)
Skeletal muscle mass (kg)	1.02 (0.94 to 1.11)	1.09 (0.87 to 1.37)	1.01 (0.91 to 1.12)
Current smoking (Yes=1, No=0)	4.97 (1.43 to 17.29)*	88.37 (2.66 to 2941.95)*	4.26 (0.86 to 21.07)
Current alcohol consumption (Yes=1, No=0)	3.13 (1.04 to 9.45)*	1.58 (0.08 to 33.18)	4.79 (1.21 to 18.99)*
Moderate exercise habit (Yes=1, No=0)	0.75 (0.30 to 1.87)	0.50 (0.03 to 7.73)	0.75 (0.26 to 2.15)
Living alone (Yes=1, No=0)	3.76 (1.18 to 11.93)*	19.47 (1.32 to 286.59)*	1.73 (0.18 to 16.90)
Psychiatric drug use (Yes=1, No=0)	1.56 (0.39 to 6.19)	46.80 (1.21 to 1806.38)*	0.61 (0.07 to 5.72)
Diabetes mellitus (Yes=1, No=0)	0.71 (0.15 to 3.43)	0.64 (0.04 to 11.75)	0.78 (0.09 to 7.06)
Hypertension (Yes=1, No=0)	0.99 (0.39 to 2.53)	1.44 (0.20 to 10.28)	0.40 (0.08 to 1.95)
Fracture history?Yes=1, No=0)	2.02 (0.89 to 4.56)	2.76 (0.31 to 24.47)	2.88 (1.04 to 7.96)*
Fall history (Yes=1, No=0)	2.66 (1.20 to 5.89)*	4.06 (0.66 to 24.95)	2.74 (1.00 to 7.46)*
Anaemia (Yes=1, No=0)†	3.63 (1.49 to 8.84)**	6.70 (0.93 to 48.30)	2.95 (0.90 to 9.69)
Albumin (mg/dL)	0.61 (0.11 to 3.46)	0.22 (0.01 to 20.09)	1.40 (0.16 to 12.50)
QUS-C-derived BUA (dB/MHz)	1.00 (0.98 to 1.03)	0.93 (0.88 to 0.99)*	1.02 (0.99 to 1.06)

The incidence of falls was 29.0 per 1000 person-years in the ≥40 year old group, 41.0 per 1000 person-years in the ≥70 year old group, and 23.5 per 1000 person-years in the 40–70 year old group.
*p<0.05, **p<0.01.
†Anaemia in men if haemoglobin (Hb) <13 g/dL, and in women if Hb <12 g/dL.
BUA, broadband ultrasound attenuation; QUS-C, calcaneal quantitative ultrasound.

confirm a trivial but important role of QUS-C-derived BUA in predicting the incidence of future falls. QUS-C-derived BUA can be used to predict fall-related osteoporotic fractures,[18–22] which might be partially mediated by its association with falls, as shown in Ou *et al*[11] and in the present study.

The mechanism that explains why a lower QUS-C-derived BUA yielded a higher incidence of falls is unclear. Deterioration of lower-limb stability is a predictor of future falls.[36] QUS-C-derived BUA has been proposed as a surrogate of muscle power and stability in the lower limbs, for example, quadriceps muscle strength.[10] Bone status measured using QUS-C-derived BUA has also been positively associated with low gait speed in community-dwelling postmenopausal women.[10] Poor mobility, however, is a risk factor for falls.[37] In our study, participants >70 years old did not even have moderate exercise habits; thus, the lower QUS-C-derived BUA might reflect lower-limb instability and relatively poorer mobility in elderly people. Hence, it is reasonable to claim an independent effect of QUS-C-derived BUA on the incidence of falls. However, additional investigations are required to confirm this finding. Practically, QUS-C-derived BUA is portable, cheap, non-radioactive and can be easily and safely used to prevent falls among community-dwelling individuals.

This study has some limitations. First, the participants were recruited from suburban and rural communities in central western Taiwan. The findings probably cannot be generalised to metropolitan or other communities. Second, only QUS-C-derived BUA was used to determine the relationship with the incidence of falls. Theoretically, QUS-C-derived BUA from non-weight-bearing sites (radial or tibial) might have no relationship with falls. Whether the QUS-C-derived BUA measured using other brands or at different sites would yield similar findings is unknown and warrants further study.

Conclusion

We found that the incidence of falls in the 40–70 year old group was higher and had different associated risk factors than in the ≥70 year old group, and that QUS-C-derived BUA can be conveniently used to predict the incidence of falls that will lead to osteoporotic fractures in potential fallers >70 years old. Clinically, the more potential fallers who can be found before they fall, the more fall-prevention programmes can be efficiently applied. When using QUS-C-derived BUA to screen for osteoporosis, preventing falls might also be possible.

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Contributors L-CO wrote the paper. C-HW wrote and revised the paper. L-CO and C-HW had the idea for the study and were involved in all aspects of this study. L-CO recruited the study participants. Y-FC, J-CC and C-SC helped interpret the data and made statistical suggestions. Z-JS, C-HW, T-HC and R-ML coordinated the study affairs and budget. All authors reviewed and approved the final version of this manuscript.

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